INFLUENCE OF GAMMA RADIATION ON WHEAT AND FLOUR PROPERTIES

By

SING-PING LAI

B.S., National Taiwan University, Taipei, Formosa, 1954

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1958

TABLE OF CONTENTS

INTRODUCTION

The possibility that ionizing radiations could be used to sterilize food became apparent 60 years ago with the discovery of x-rays. This field, however, has not been explored until recently when particle accelerators were developed and radioactive materials producing ionizing radiations became available. From the standpoint of efficiency of production, penetration, and safety, apparently only gamma-rays from nuclear reactions and cathode rays from particle accelerators are suitable as sources of ionizing radiation for sterilization purposes. Large amounts of radioactive fission by-products from the operation of nuclear reactors and atomic piles are being constantly produced by the Atomic Energy Commission. Widespread investigations concerning the utilization of these waste products as sources of radiation for sterilizing and thus preserving foods are underway in the United States.

Considerable information on the control of insect infestation in grain by ionizing radiation has been published elsewhere (25, 26, 49). Previous work in this laboratory has indicated that gamma-radiation treatment of wheat at dosages between 125,000 rep and 625,000 rep was sufficient to eliminate fungal respiration in the grain without changes in fatty acid content or in the fluorescence of acid extracts of grain (60). Preliminary studies were also carried out in this laboratory on the effect of gamma-irradiation of wheat on the baking properties of flour. Relatively little information has been published, however, in regard to overall effects of gamma-irradiation on flour milled from treated wheat.

The purpose of the present study was to investigate in greater detail the effects of gamma-irradiation of wheat on certain chemical, physical and baking characteristics of flour milled therefrom.

HISTORICAL REVIEW

Production of Ionizing Radiations and Their Properties

The term "radiation" usually indicates a physical phenomenon in which energy travels through space even though that space may be empty of matter.

There are two kinds of radiations namely:

(1) Corpuscular radiations are streams of various kinds of atomic or subatomic particles, which can transfer their kinetic energy to anything they hit.

(2) Electromagnetic radiations are self-propagating magnetic disturbances, which affect the internal structure of matter and thus their energy is dissipated.

Table 1 illustrates a classification of biologically important radiations. Corpuscular radiations are classified according to the nature of the constituent particles. The classification of electromagnetic radiations is more practical.

Table 1. Classification of biologically important radiations (27)

Corpuscular			Electromagnetic		
Electrically charged		Electrically neutral			
Light	Heavy				
Cathode rays (electrons), positrons	Protons, deutrons, and other ion beams	Neutrons	Radio waves micro-waves	Light (infra-red visible and ultraviolet.)	X-rays
Special names of radiations from atomic nuclei					
Beta-rays (-)	alpha-rays (+) beams of heliumions				Gamma-rays

Production of high-energy charged particles normally involves the use of a machine. Electrons are usually accelerated to high energies by means of Van de Graaff generators, resonant transformers or linear accelerators. These electrons may be used directly or may be caused to impinge upon a metal target for the production of high energy x-rays.

Electromagnetic radiation may be produced by an x-ray machine described above, or by radioactive isotopes. Concerning the latter, radioactive cobalt (Co^{60}) and fission by-products have been used extensively. Small cobalt capsules have been irradiated in reactors to produce suitable cobalt gamma radiation sources. Radioactive fragments suitable for irradiation work may be from a spent uranium slug under suitable conditions.

The operation of reactors or piles such as in nuclear power plants results in the accumulation of very large quantity of waste radioactive elements. Isotopes generating both gamma and beta radiations can be extracted from these wastes. This source of radiation now is largely unused.

Mechanism of Radiation Action

Ions and excited molecules produced by radiations are precursors of observed chemical effects. All ionizing radiations utimately transfer energy to an irradiated system by means of particles. In the case of gamma-rays, the effective particles are high energy electrons ejected by the interaction of photons with atoms. After the formation of primary ions and excited molecules, many secondary processes may occur before final chemical changes such as transfer of excitation and ionization between like or unlike molecules, neutralization of ions, formation of negative ions, with or without de-

composition to radicals or molecules, and the disruption of excited molecules to radicals or new molecules.

Essentially there are two types of radiation effects on substances, namely, the direct "hit" reaction and the indirect reaction. The direct "hit" may be responsible for some specific biological effects, but many effects are caused in whole or in part by a solvent if one is present.

The indirect reaction had already been suggested in 1930 by Risse (51) in his "activated solvent" hypothesis, and was later developed by Fricke (23). Weiss (58, 59) suggested a series of reactions which might occur when water is irradiated with x-rays. The products first formed are the positive ion H_2O+ and an electron.

$$H_2O \xrightarrow{\text{radiation}} H_2O+ \ + e$$

Because of the high energy of hydration of H+, the reaction is highly exothermic.

$$H_2O \longrightarrow H+ \ + \ OH$$

The electron which was set free with ionization will react with water.

$$H_2O + e \longrightarrow H_2O-$$

Decomposition of the H_2O- ion by the exothermic reaction will give:

$$H_2O- \longrightarrow H + OH-$$

The following further reactions are possible:

$$OH + OH \longrightarrow H_2O_2$$

$$H + H \longrightarrow H_2$$

$$OH + OH \longrightarrow H_2O + O$$

$$2\ O \longrightarrow O_2$$

$$H_2 + OH \longrightarrow H_2O + H$$

$$H + O_2 \longrightarrow HO_2$$

$$HO_2 + HO_2 \longrightarrow H_2O + O_2$$

$$HO_2 + H \longrightarrow H_2O_2$$

When oxygen is present in water there may occur:

$$O_2 \longrightarrow O_2^- \longrightarrow O_2^=$$

In water, where protons can be added, these would be converted to:

$$O_2 \longrightarrow O_2H \longrightarrow O_2H_2 \longrightarrow OH + OH_2 \longrightarrow 2OH_2$$

Reduction of molecular oxygen would thus produce in addition to atomic oxygen, three powerful oxidizing agents: the radicles OH, O_2H, and H_2O_2.

Effect of Ionizing Radiations on Carbohydrates

When carbohydrates are irradiated in aqueous solution, the secondary alcohol groups are found to be uneffected, while the primary alcohol groups are oxidized to aldehyde (46). There are indications that hexoses yields the corresponding uronic acids on irradiation, probably because the primary alcohol group is oxidized to give an unstable dialdose which changes to the hexuronic acid. Sucrose is inverted by irradiation in aqueous solution (15). There are also indications that glucose gives other substances as well as glucuronic acid on irradiation, but little is known of their nature (Clark and Pickett, 15).

Starch, agar-agar, and gum arabic showed viscosity decreases in aqueous solution after irradiation. The formation of reducing substances and decrease of pH value has also been demonstrated (18, 50, 54).

High energy cathode rays converted potato starch to dextrin, glucose and fructose at a dosage level of 5×10^6 rep (Roberts, 52). Fragmentation of the starch of flour to the stage of carbon monoxide has been observed by Gilles et.al. (24).

When cellulose is irradiated in the dry state, it is degraded into water-

soluble products including reducing sugars, thereby rendering it more susceptable to acid hydrolysis (14, 33, 53).

The degradation of dextran by radiation is accompanied by an increase in branching and a rupture of the glucose rings. Each of these reactions is accompanied by the production of two reducing end groups (Price et al, 47).

Dry sugar after irradiation with 1 to 10 x 10^7 reps showed a 2 to 14% per unit decrease in copper reduction value. These losses can be attributed to the formation of oxidation products since the treatment occurred in air (48, 53).

Effect of Ionizing Radiations on Proteins

Protein denaturation by radiation which has been known for years, occurrs on treatment with large doses and is different from that produced by acid and alkali. The coagulum produced from irradiated serum albumin could not be converted into a water soluble product by treatment with alkali and subsequent dialysis (Spiegel, 56). The addition of electrolytes to protein solutions accelerated the irradiation induced denaturation process. The coagulation of egg albumin by radiation occurred much more rapidly in the presence of ammonium sulfate (Bovie, 13). However, Barron et. al. (7) reported that sodium chloride, sodium bromide, sodium nitrate and sodium thiocyanate had an obvious protecting effect on the change of absorption spectrum of proteins caused by radiation. A few investigators (7, 56) have reported that denaturation occurred only if the pH of the solution was near the isoelectric point. Viscosity and sedimentation rate of proteins were also changed by radiation.

Irradiation of homocyanin results in the splitting of the protein molecules

into half molecules. Hemoglobin and serum albumin also show a lower molecular weight upon radiation at room temperature (Svedberg and Brohult, 57).

The viscosity of gluten sol decreases linearly with increased radiation dosage (Lloyd, et. al. 34). This phenomena suggests that the gluten proteins are broken into shorter or more symmetrical molecules.

Gilles and co-workers (Gilles, et. at., 24) observed gluten denaturation, after exposure to gamma-radiation, as indicated by reduction in gluten recovery, increased solubility, farinogram characteristics of synthetic doughs and changes in sulfhydryl titration.

The most obvious and well known effect of ionizing radiation upon amino acid is deamination. The amount of ammonia production is highly related to pH value, concentration of amino acid, radiation dosage level and the presence of oxygen (Dale, 17).

Hydrogen sulfide has been detected after irradiation of cysteine hydrochloride or glutathione in its reduced form. The yield is dependent on the hydrogen ion concentration and x-ray dose (17).

Barron et. al (6, 8) observed that dilute solutions of sulfhydryl enzymes (phosphoglyceraldehyde dehydrogenase, adenosine triphosphatase) showed reduced activity on irradiation with small amounts of x-rays. When the inhibition was partial the enzyme was reactivated on addition of glutathione, but if the inhibition was more complete reactivation was only partial. The products of ionization of water may oxidize sulfhydryl groups which is required for enzyme is inhibited on irradiation through oxidation of its sulfhydryl groups to the disulfide, the following reversible oxidations could occur.

$$2RSH + 2OH \rightleftharpoons R\text{-}S\text{-}S\text{-}R + 2OH^- + 2H^+$$

$$2RSH + 2O_2H \rightleftharpoons R\text{-}S\text{-}S\text{-}R + 2H_2O_2$$

$$2RSH + H_2O_2 \rightleftharpoons R\text{-}S\text{-}S\text{-}R + 2H_2O$$

$$2RSH + 2O \rightleftharpoons R\text{-}S\text{-}S\text{-}R + H_2O$$

It would appear possible to reduce the disulfides by addition of glutathione and thus restore enzyme activity.

Effect of Ionizing Radiation on Wheat

Wheat seeds showed an increase in diastase activity and sugar content after irradiation for five seconds with the characteristic K lines of copper. If irradiated for a longer time, a regular decrease in those two substance and the respiratory rate was observed (Benedict and Kersten, 11). Bassenge (9) reported that the substitution of irradiated wheat protein for non-irradiated in the diet of white rats was without significant effect on the nitrogen balance. The urinary quotients decreased significantly, however, indicating that in the intermediary metabolism of irradiated protein the various fragments involved undergo more complete oxidation than those arising from non-irradiated protein. The effect of ionizing radiation on the biological properties and induced mutation has been the subject of some investigation (4, 31). Afanaseva (1) reported that x-rays caused a strong germinative stimulation of wheat grains (Triticum durum) at dosage of 8,000 to 10,000 rep. The germinated grain was most sensitive, the moist seed even weaker, and the air-dried seed was more resistant to stimulating effect by radiation. Yen et al (60) have indicated that gamma-radiation treatment of wheat at dosages between 125,000 rep and 625,000 rep was sufficient to eliminate fungal respiration in grain without changes in fatty acid content or in fluorescence of acid extracts of the grain. Germination was reduced significantly at

dosage as low as 25,000 rep. The colloidal properties of wheat proteins were damaged by strong doses (625,000 rep).

Effect of Ionizing Radiations on Flour

The investigations of Maes and co-workers (35, 40) on the effect of ultraviolet rays on flour led them to conclude that baking quality was improved. The enzyme activity was increased. These workers also observed a change of chromatographic R_f values of some amino acids, the changes in the reducing power of starch; and increased growth of rats fed with the irradiated flour as a result of an increase in the biological value of the protein complex.

Brownell, et. al. (12) observed that cake flour, all-purpose, and bread flour were not changed when given a dose of 20,000 rep gamma-radiation. Bread with flours receiving higher dosages were progressively poorer. The breads were baked by the technique of the housewife rather that that of the commercial bakery.

In a recent publication, Bauman et. al. (10) indicated that a radiation level of 1×10^5 rep was required for reduction of bacteria in white cake batter, but color, odor and the baking characteristics of cake batter were markedly changed with this treatment. An appreciable reduction of bacterial numbers was obtained in white and spice cake mixes receiving a dose of 5×10^4 rep. At 5×10^4 rep the spice and white cake showed slight off-flavor, slight off odor, and compactness. One million rep caused marked changed in color, odor and gelatinization properties of dry cake mixes.

The work of Milner and Yen (43) showed that flours from wheat treated with increasing levels of radiation were of progressively lower sedimentation value, gelatinization viscosity, and higher maltose value. Physical dough tests indicated that radiation decreased dough development time with mixing and increased rate of break-down following optimum development. The alveograph tests revealed that dough stiffness was increased by radiation, whereas extensibility was decreased. They also observed a minor improvement of loaf quality at 125,000 rep which appeared comparable to that produced by potassium bromate. Characteristic changes of irradiated flour were also found by Gilles et. al. (24). McWilliams et. al. (41) observed a darkening in stored bread baked from irradiated flour.

A recent review of radiation preservation of foods by Morgan (44) discloses that flour can be made insect free with dosages ranging from 30,000 to 70,000 rep. After storage for 9 months at 100°F satisfactory bread could be produced. After exposure to 150,000 - 250,000 rep and 42 days of storage at 40 - 60°F biscuit doughs lost elasticity and produced baked biscuits with obviously off odor.

SUMMARY OF LITERATURE

The literature discloses extensive investigations concerning the basic chemical and biochemical mechanism of radiation action as well as its effect on the major wheat flour components such as carbohydrates and proteins. Considerable information has also been published dealing with the effect of radiation on wheat infestation, fungal respiration, wheat composition and various other properties. Relatively little literature exists however, about the chemical, physical and technological changes in flour milled from wheat treated with dosages beyond those required to kill insects.

STATEMENT OF PROBLEM

The purpose of the present study was to investigate in detail the effects of gamma-irradiation of wheat on certain chemical, physical and baking properties of flour milled from treated wheat.

Wheat samples were irradiated at various dosage levels ranging from 0 to 1.0×10^6 rep and then milled. Investigations included examination of various chemical and physical properties including fat acidity, sugar content, color change, hydration capacity of gluten, starch gelatinization, physical dough properties and seed viability. The baking properties were evaluated both by pup-loaf baking test and commercial one-pound loaf baking test. Studies on bread color and compressibility were also carried out with commerical-scale loaves. Bread taste evaluation involved statistical analysis of the results from a panel of seven judges.

MATERIALS AND METHODS

Wheat and Flour Samples

The three wheat samples used included a Hard Red Winter (Bison variety) obtained from Colby Experimental Station, Colby, Kansas, Hard Red Spring (Conley variety) obtained from North Dakota, and Hard Red Winter (Comanche variety) obtained from the Agronomy Farm, Kansas State College, Manhattan, Kansas. These wheats were characterized as follows:

	Protein %	Moisture %	Ash %
Bison	14.1	10.1	1.53
Conley	14.4	9.7	1.53
Comanche	14.2	11.88	1.79

These dry wheats were sealed in No. 2 metal cans and sent to the Materials

Testing Reactor, Idaho Falls, Idaho, for radiation treatment at the following levels:

Pison

Sample Code No.	Radiation Dosage 10^6 rep	Exposure Time
2101	Control	----
2102	0.05	1 min. 6 sec.
2103	0.10	2 min. 12 sec.
2104	0.15	3 min. 18 sec.
2105	0.20	4 min. 24 sec.
Rate:	2.73×10^6 rep/hr.	

Conley

Sample Code No.	Radiation Dosage 10^6 rep	Exposure Time
2106	Control	-----
2107	0.1	1 min. 52 sec.
2108	0.3	5 min. 31 sec.
2109	0.6	11 min. 24 sec.
2110	1.0	18 min. 22 sec.
Rate:	3.27×10^6 rep/hr.	

Comanche

Sample Code No.	Radiation Dosage 10^6 rep	Exposure Time
2111	Control	----
2112	0.1	2 min. 42 sec.
2113	0.3	8 min.
2114	0.6	16 min.
2115	1.0	27 min.
Rate:	2.24×10^6 rep/hr	

Yen and Milner (43, 60) indicated that a dosage level somewhere between 125,000 and 625,000 rep applied to wheat would be sufficient to eliminate the insect and fungal respiration. The lowest of these dosages apparently caused a minor improvement in the baking characteristics of flour. In order to confirm these latter findings, dosage levels ranging from 0 to 200,000 rep were

chosen for Bison variety. Baking tests failed to confirm the improvement indicated by Milner and Yen, therefore, higher dosage levels ranging from 0 to 1.0 x 10^6 rep were used in the subsequent studies with Conley and Comanche wheat. The irradiated cans of wheat were opened and mixed well for a half hour. The wheat was tempered to 15% moisture and milled in the Buhler experimental mill. The flour was well mixed for 30 minutes and stored at room temperature for further studies. The milling results, as shown in the Table 1 indicated no apparent difference among various samples due to irradiation treatment.

Table 1. Milling characteristics of irradiated wheats

Code No.	Radiation dosage	Quantity milled	Flour	Bran & shorts	Flour yield
	10^6 rep	lb.	lb.	lb.	%
		Bison variety			
2101	0	47.2	32.9	11.6	69.8
2102	.05	46.5	32.6	10.6	70.1
2103	.10	47.0	32.6	10.9	69.4
2104	.15	46.7	33.1	11.3	71.0
2105	.20	46.8	32.3	11.2	68.8
		Conley variety			
2106	0	20.0	13.7	5.4	68.7
2107	0.1	19.0	13.1	5.7	68.7
2108	0.3	19.0	13.2	5.2	69.4
2109	0.6	19.0	12.9	5.5	68.1
2110	1.0	19.0	12.6	5.7	66.4
		Comanche variety			
2111	0	46.9	31.0	14.0	66.1
2112	0.1	47.0	28.6	13.7	60.9
2113	0.3	46.8	30.4	13.8	64.9
2114	0.6	46.7	30.7	13.5	65.6
2115	1.0	46.6	29.8	14.1	63.9

Analytical Methods

Moisture, protein, ash, reducing sugar, non-reducing sugar contents, and maltose value of flours were determined according to the procedure described in Cereal Laboratory Methods (2). Thiamine, riboflavin and starch (polarometric) were determined according to the procedure as outline in A.O.A.C. (5) by the Chemical Service Laboratory, Kansas State College, Manhattan, Kansas.

Fat Acidity

Ten grams of flour sample were extracted continuously in the Goldfish extractor with 50 ml of SkellySlove (petroleum ether) for six hours. After removal of the solvent, the extract was dissolved in 10 ml of isopropyl alcohol benzene mixture (2). Titration was with KOH solution (0.01N in anhydrous isopropanol) with phenolphthalein as indicator. Fat acidity was reported as mg KOH required to neutralize the fatty acids in 100 gm of flour.

Dextrin Content

The method of Miller et. al. (42) was employed to determine the amount of dextrin in flour and the average dextrin chain length. A fifty gram sample of flour was extracted with 250 ml of water (30°C). The water extract was autoclaved for 20 minutes to destroy residual enzyme activity and then fermented for 18 hours with baker's yeast (Saccharomyces cerevisiae), so as to eliminate fermentable sugar. The dextrin was precipitated by adding 95% ethanol (extract/ethanol = 1 / 3 by volume). One aliquot of the precipitated dextrin was filtered through a Gooch crucible and weighed after drying for 2 hours at 130°C. Another portion of the precipitate was redissolved in

water. To determine reducing groups both before and after acid hydrolysis with 0.5 N H_2SO_4, autoclaving was carried out under 15 lb. pressure for 30 minutes. Dextrin chain length was calculated by dividing the number of reducing groups determined after hydrolysis by the number existing before hydrolysis.

Fluorescence Test

This test provides a semi-quantitative evaluation of the extent of Maillard or browning reaction. The procedure as described by Cole and Milner for wheat (16) was followed. Two grams of wheat sample, ground in the intermediate Wiley mill and sieved through the No. 30 screen, were extracted with 15 ml of 0.186 N. HCl for 45 minutes, with shaking every 15 minutes. The mixture was then centrifuged at 1500 r.p.m. for five minutes and filtered. The extract was clarified by adding 5 ml chloroform, shaking for 1 minute, and recentrifuged for 15 minutes. Two ml of the clear supernatant solution was diluted to 50 ml with 0.186 N HCl. The Coleman Electronic photofluorimeter with vitamin B_1-S and PC-1 filters transmitting at 345 mm was used for measurement. The instrument dial was set to 60 with a 0.075 p.p.m. sodium fluorescein standard. A solution of 0.186 N HCl was used as a blank.

Paper Chromatography of Sugars

Extraction of sugars from flour was accomplished as outlined by Koch, et. al. (32). Fifty grams of flour sample were suspended in 100 ml of boiling 70% aqueous ethanol and heated to 80°C for 7 minutes to inactivate enzymes. The mixture was cooled, centrifuged, and the supernatant withdrawn. The flour residue was then extracted once with 100 ml of 30% aqueous ethanol and three

times with 100 ml of distilled water; the extraction was carried out at room temperature, all extracts were combined and the volume measured. The extract was made to 20 per cent alcohol content, and transfered to an Erlenmeyer flask. A small cellophane casing (9/16 inches inflated diameter) containing 10 ml of 20 per cent aqueous ethanol was placed in the extract. Dialysis proceeded with the aid of a magnetic stirrer for 20 hours. The solution in the Visking casing was then evaporated by air to give a syrup-like mixture. The latter was then dissolved in 1.0 ml water. Ten gamma portions of the aqueous solution of the syrup mixture were subjected to descending paper chromatography using a mixture of 70 ml propanol, 10 ml ethanol and 20 ml water as a developing solvent and p-anisidine-HCl as detecting agent (Mukherjee, 45).

Pigment Content

Flour pigment was determined by measuring the optical density of n-butyl alcohol flour extracts with the Beckman spectrophotometer (3).

Sedimentation Test

This is a test for hydration capacity of gluten in flour. It was carried out according to instructions in Cereal Laboratory Methods (3).

Flour Color Grade

The Kent-Jones flour color grader was used for measuring flour color (Kent-Jones, et. al., 30). This instrument utilizes a balanced circuit containing two photoelectric cells to measure light of a specific wave-length reflected from the surface of a paste prepared from 30 gms of flour and

50 ml of water. The amount of light reflected by the flour depends on the quantity and nature of the bran powder and on pigment content, but not on the granularity of the sample.

Amylograph

Starch gelatinization viscosity was determined using the Brabender Amylograph over a temperature range of 30°C to 90°C (Johnson, 29). A ratio of 65 grams and 75 grams flour to 460 ml buffer solution were used for Bison and Conley varieties respectively.

Farinograph Curves

They were determined by means of the Brabender farinograph using the constant flour weight method (3).

Gas Production in Doughs

The Pressuremeter method was used as directed in Cereal Laboratory Methods (2). Readings were taken every 15 minutes for first hour and every half hour for four additional hours.

Non-protein Nitrogen

One gram flour sample was extracted with 40 ml, 0.8 N. trichloroacetic acid for half an hour, and stirred occasionally. The suspension was centrifuged for 10 minutes at 1500 r.p.m. 25 ml of the clear supernatant liquid was used for nitrogen determination by Kjeldahl-Gunning-Arnold Method (3).

BAKING PROCEDURE

Pup Loaf Baking Test

Pup loaf baking tests were carried out using a straight dough method as developed by Finney (19-22) with four different formulas, namely, (1) rich formula including all necessary ingredients as shown in the following list, (2) same formula without malt, (3) same formula without sugar and (4) same formula without sugar and malt.

Modifications in formula as indicated in 2, 3, 4 above were made in order to clarify the effect of starch modification due to radiation on baking properties.

Baking Ingredients	Weight (g)
Flour	100 (on 14% moisture base)
Milk	4
Shortening	3
Sugar	6
Salt	1.5
Malt	0.25
Yeast	2.125
$KBrO_3$	as required (mg/100 g flour)
Water	as required

The mixed dough was fermented at 86°F and 96% relative humidity, with a first punch at 1 hour 45 minutes, and a second punch after an additional 50 minutes. Twenty-five minutes later the dough was panned, proofed for 55 minutes at 86°F and 96% relative humidity, and then baked for 24 minutes at 425°F.

Commercial One-Pound Loaf Baking Test

The commercial one pound loaf was baked by sponge dough procedure. The sponges were mixed for two minutes in a "Hobart A-200" mixer and fermented for

four hours at 84°F to 86°F and 90-92% relative humidity. They were then remixed with the balance of the dough ingredients to the point of optimum development. The remixed doughs were allowed a thirty minute floor times, scaled to twenty ounces, and given twenty minutes rest before moulding with a "Century" moulder. The loaves were proofed at 92°F and 95% humidity. Baking was carried out for 24 minutes at 425°F.

A total of 700 grams of flour was used for each mix. The following baking formula was employed:

Ingredients	Sponge %	Dough %
Flour	70	30
Yeast Food (Arkady)	0.5	--
Malt	0.5	--
Yeast	2.0	--
Water	45.7	As required
Sugar	----	5
Salt	----	2
Dry solid milk	----	4
Shortening	----	3

Compressibility Measurements of Bread

Compressibility of bread crumb was expressed as weight required to depress a one inch-plunger 4 mm into two ½ inch thick slices of commercial one pound bread by means of the Bloom Gelometer. Three determinations on each of two of the four slices of bread of each experimental group cut by an Oliver bread slicer. were recorded after storage for 2 and 24 hours. Four replicates of the compressibility of the bread baked on different days from irradiated Comanche wheat were determined.

The Taste Panel Test

One pound regular commercial loaves produced from irradiated Comanche wheat of various dosage levels were examined by seven taste testers on the

next day following baking. The breads were wrapped in wax paper and stored at room temperature until used. The form used by the judges was as follows:

Date__________
FLAVOR RATING   Signed__________
Best__________
2nd Best__________
3rd Best__________
4th Best__________
5th Best__________

Please rate each of the five according to FLAVOR preference.

All samples were coded in a random fashion, a new code being used for each day. Six panel tests were carried out every other day. Results were analyzed statistically (Snedecor, 55).

Bread Color Test

The Photovolt reflection meter was used to test the bread color using a green filter, and a white enamel disc served as a working standard. The reflectance was expressed in per cent of the reflection from a magnesium oxide reference standard.

EXPERIMENTAL RESULTS

Chemical and Physical Properties of Flour Milled from Irradiated Bison and Conley Wheat

Tables 2 and 3 provide a comparison between the chemical and physicochemical properties of flours milled from Bison and Conley wheats treated with various irradiation dosage levels.

Slight increase in reducing and non-reducing sugar content of flour was found in both flour samples. Maltose values increased with increasing radiation

Table 2. Chemical and physical properties of flour milled from irradiated Bison wheat.

Determination	0	Radiation dosage, 10^6 rep 0.05	0.10	0.15	0.20
Protein, %	13.0	13.1	13.0	13.0	13.1
Moisture, %	11.4	11.2	11.3	11.0	11.0
Ash, %	0.45	0.45	0.45	0.45	0.45
Reducing sugar 1/	133.5	154.5	166.5	170.0	170.0
Non-reducing sugar 2/	275.5	305.5	305.5	305.5	305.5
Maltose value 3/	192.2	226.8	227.4	235.2	238.4
Dextrin 4/	871.5	1002.2	1043.3	1106.6	1206.0
Fatty acids 5/	15.2	14.5	13.5	13.2	13.2
Fluorescence units	25	24	23.8	24	24.2
Non-protein nitrogen 4/	158	158	175	195	228
Starch, %	71.1	68.9	68.9	69.7	69.7
Riboflavin 4/	0.056	0.033	0.032	0.041	0.046
Farinograph data					
Absorption, %	73.2	74.9	75.5	75.1	75.0
Dough devel. time, min.	7.5	7	7.5	7	5.5
Mix. tolerance index 6/	50	48	60	50	60
Max. amylograph visc. 6/	980	650	560	490	420
Sedimentation value	35	33	33	31	34

1/ Milligrams maltose per 10 g. flour.
2/ Milligrams sucrose per 10 g. flour.
3/ Milligrams maltose per 10 g. flour per hour at 30° C.
4/ Milligrams per 100 g. flour.
5/ Mg. KOH/100 g. flour.
6/ B.U.

Table 3. Chemical and physical properties of flour milled from radiated Conley wheat.

Determination	0	Radiation dosage, 10^6 rep 0.1	0.3	0.6	1.0
Protein, %	12.9	13.1	12.9	13.0	12.9
Moisture, %	11.5	11.6	11.6	11.9	11.7
Ash, %	0.43	0.43	0.43	0.43	0.43
Reducing sugar1/	173	184.4	184.4	184.4	190.8
Non-reducing sugar2/	272.5	282.5	282.5	282.5	287.5
Maltose value3/	454.5	461.5	499	542	550
Dextrin4/	1048.4	1374.6	1639.6	1655.9	1678.1
Dextrin reducing matter5/					
Before acid hydrolysis	32.8	80.3	141.2	152.7	171.3
After acid hydrolysis	368.5	390.2	531.5	595.3	654.1
Glucose units in dextrin	12	5	4	4	4
Fatty acid	13.2	12.9	12.6	12.3	12.3
Fluorescence units	27	28	28	29	31
Pigment content6/	13.7	12.9	12.4	11.6	10.5
Starch, %	70.1	66.7	68.6	67.5	62.3
Riboflavin4/	0.023	0.022	0.018	0.027	0.050
Thiamine4/	0.414	0.483	0.426	0.257	0.174
Sedimentation value	66	57	53	51	47.5
Flour color	2.77	3.40	3.46	3.69	3.95

Table 3. (concl.)

Determination	Radiation dosage, 10^6 rep 0	0.1	0.3	0.6	1.0
Max. amylograph visc.7/	950	650	310	200	90
Farinograph data					
Absorption %	72.8	73.5	74.4	75.0	75.1
Dough devel. time, min.	$8\frac{3}{4}$	8	7	6	$6\frac{1}{2}$
Mix. tolerance index7/	25	30	25	35	45

1/ Milligrams maltose per 10 g. flour.
2/ Milligrams sucrose per 10 g. flour.
3/ Milligrams maltose per 10 g. flour per hour at 30° C.
4/ Milligrams per 100 g. flour.
5/ Milligrams maltose per g. dextrin.
6/ Milligrams carotene per 100 g. flour.
7/ B.U.

treatment. It readily can be seen that as the dosage increases, the maximum viscosity of starch gelatinization (amylograph test, Fig. 1 and 2) decreased considerably. The amount of dextrin with short average glucose chain length was obviously higher in treated flour than in untreated flour. The chromatographic analysis showed no change in amount or kinds of simple sugars, as determined by subjective visual comparison of color intensities and areas of spots.

No significant change of fatty acid content was detected. Fluorescence was unchanged in the Bison series (maximum dosage 200,000 rep) but showed a slight increase with 1 x 10^6 rep treatment in the Conley variety, indicating that this high irradiation level caused browning to occur.

The loss of swelling properties of flour gluten was shown by the decrease in sedimentation value of flour milled from irradiated Conley wheat. However, the flour with higher dosage contained a lower carotenoid pigment content.

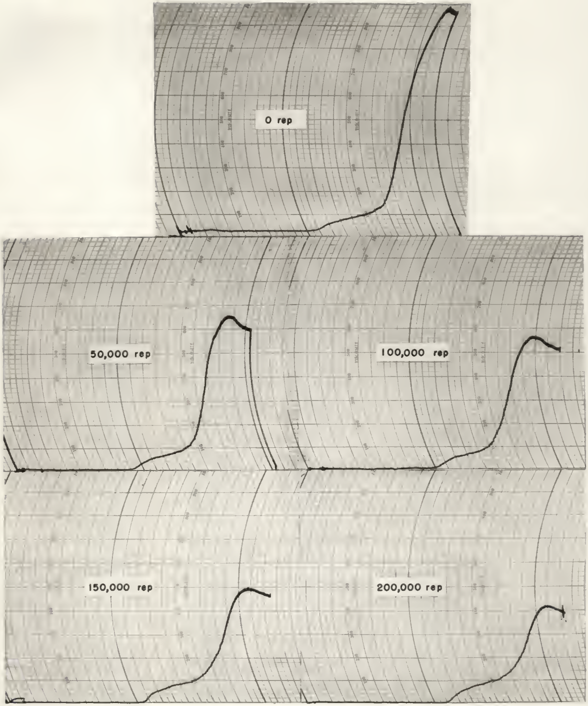

Fig. 1. The effect of gamma-radiation on amylograms of Bison wheat flour.

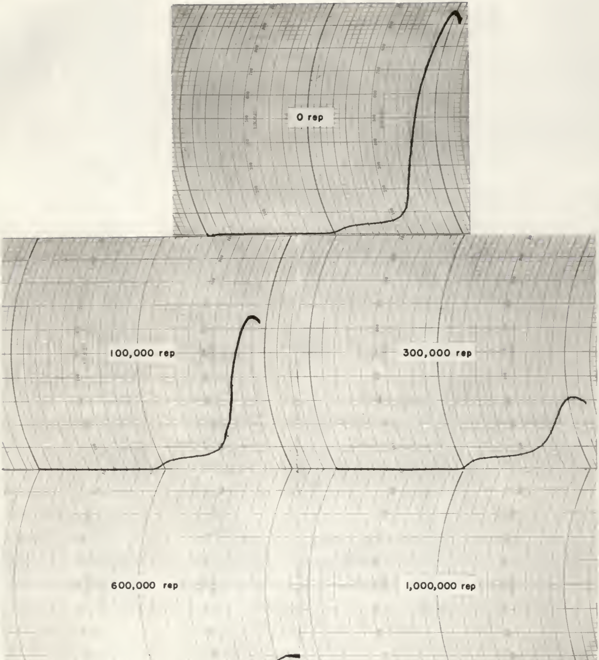

Fig. 2. The effect of gamma-radiation on amylograms of Conley wheat flour.

The farinograph data (Figs. 3 and 4, Tables 2 and 3) revealed an increase in water absorption and a decrease in dough development time of treated flour.

Mixing tolerance index, measured as the decrease in consistency 5 minutes after attainment of maximum dough development time or peak, remained approximately constant in the Bison series, (Fig. 3 and Table 2) but showed an increase with 0.6 and 1.0×10^6 rep treatments in the Conley variety (Fig. 4 and Table 3).

Gas production data for flours milled from lots of wheat that received various radiation treatments are shown in Fig. 5. The rate of gas production of flour with a dosage of 0.1×10^6 rep was materially higher than the control after 180 minutes, and even greater at a dosage of 0.6×10^6 rep. Since the rate of gas production at dosages of 0.3×10^6 rep and 1.0×10^6 rep were practically the same as 0.1×10^6 and 0.6×10^6 rep respectively, the results obtained with these two latter dosages were omitted from Fig. 5.

Non-protein nitrogen determination for the Bison series (Table 2) increased with the radiation dosage beyond 0.05×10^6 rep. An apparent increase of riboflavin was observed in the Conley series for the 1.0×10^6 rep treatment (Table 3). The results for thiamine determination seemed questionable. There was an apparant decrease, however, at the higher dosage levels of 0.6 and 1.0×10^6 rep of the Conley series in Table 3.

No significant change of starch content was detected in either the Bison or Conley series at lower irradiation levels, but a significant decrease appeared at the highest dosage of 1.0×10^6 rep.

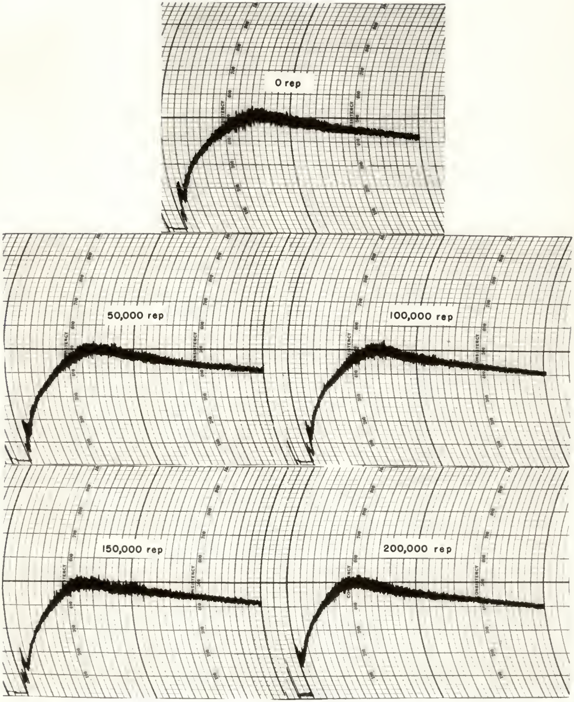

Fig. 3. Farinograms of Bison wheat flour treated with gamma-radiation.

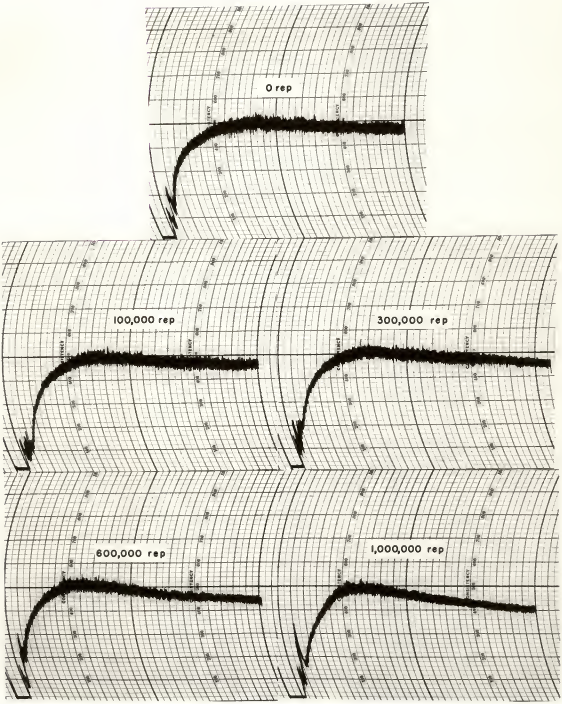

Fig. 4. Farinograms of Conley wheat flour treated with gamma-radiation.

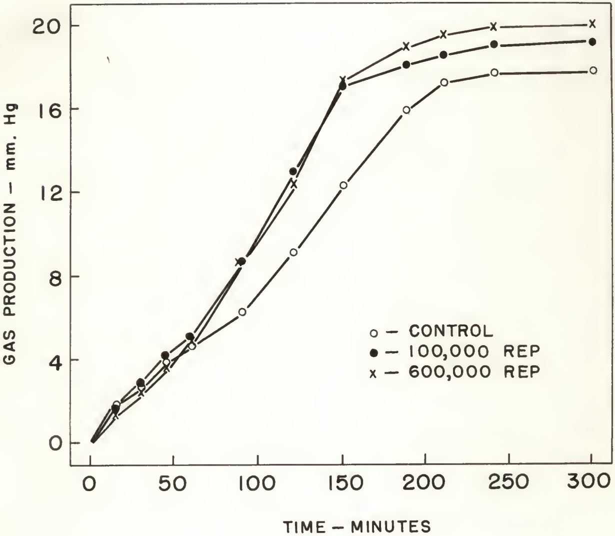

Fig. 5. The effect of gamma-radiation on rate of gas-production from Conley wheat flour.

Baking Properties of Flour Milled from
Irradiated Bison and Conley Wheats

Table 4 and 5 show a comparison of the baking quality of Bison and Conley wheat after the various irradiation and baking treatments. Figs. 6 and 7 are photographs of loaves obtained from the Bison and Conley wheats, respectively.

The breads baked from control, 0.1×10^6 rep, and 0.2×10^6 rep, irradiated Bison wheat flours revealed a progressive decrease in mixing time with increasing radiation dosages. No significant change in absorption was found. Loaf volume obtained using the rich formula but without potassium bromate showed a decrease with increasing radiation dosage. Addition of adequate potassium bromate resulted in the recovery of the loaf volume lost by radiation treatment. However, the bread produced from irradiated flour, even at optimum bromate levels, possessed an obviously open, contrastable, and relatively poor grain in comparison with the light, close, uniform grain of the control. No other significant changes due to radiation were observed in bread baked from the other three formulas in which sugar, or malt, or both sugar and malt were omitted. Radiation treatment obviously did not affect the requirement for malt and/or sugar for optimum loaf quality.

Baking absorption for Conley wheat progressively increased somewhat up to 0.6×10^6 rep, but at the maximum dosage of 1.0×10^6 rep was slightly less than the control. Mixing time decreased consistently with an increase in dosage level. Bread baked with the rich formula at zero bromate level showed a progressive reducing effect with increasing radiation dosage, in terms of lower loaf volume and poorer (under-developed) crumb grain. Crumb grains were progressively poorer with increasing dosages of radiation. For the three

Table 4. Baking characteristics of flours from irradiated Bison HRW Wheat

Radiation dosage	Absorption	Mixing time	Optimum bromate	Loaf Volume: 0 bromate	Loaf Volume: Optimum bromate	Crumb grain[1]: 0 bromate	Crumb grain[1]: Optimum bromate
10^6 rep	%	min.	mg./100 g.	ml.	ml.		
Rich Formula							
Control	69.3	$3\frac{3}{8}$	2	860	903	Q - S	Q - S
0.05	70.0	$2\frac{7}{8}$	3	---	910	---	Q
0.10	70.0	$2\frac{3}{4}$	3	863	904	Q	Q
0.15	70.0	$2\frac{5}{8}$	3	---	923	---	Q
0.20	69.0	$2\frac{3}{8}$	3	833	904	Q - U	Q
Rich Formula, Without Malt							
Control	71.5	$3\frac{3}{8}$	1 - 2	---	879	---	Q - S
0.10	72.0	$2\frac{3}{4}$	2	---	849	---	Q
0.20	71.0	$2\frac{3}{8}$	2 - 3	---	863	---	Q
Rich Formula, Without Sugar							
Control	70.5	$3\frac{1}{4}$	1 - 2	---	863	---	Q
0.10	71.0	$2\frac{5}{8}$	1 - 2	---	900	---	Q
0.20	70.0	$2\frac{1}{4}$	1 - 2	---	863	---	Q
Rich Formula, Without Sugar and Malt							
Control	73.0	$3\frac{3}{8}$	1	---	443	---	VU
0.10	73.5	$2\frac{3}{4}$	1	---	482	---	VU
0.20	72.5	$2\frac{3}{8}$	1	---	448	---	VU

1/ S, Q, U, and VU - Satisfactory, Questionable, Unsatisfactory, and Very Unsatisfactory quality with respect to property in question.

Table 5. Baking characteristics of flours from irradiated Conley HRS Wheat

Radiation dosage	Absorption	Mixing time	Optimum bromate	Loaf Volume: 0 bromate	Loaf Volume: Optimum bromate	Crumb grain[1]: 0 bromate	Crumb grain[1]: Optimum bromate
10^6 rep	%	min.	mg/100 g.	ml.	ml.		
Rich Formula							
Control	74.5	4 3/4	2	840	941	S	S
0.1	74.8	4 1/4	2 - 3	805	946	Q	S
0.3	74.9	3 3/8	3	805	565	Q - U	Q - S
0.6	76.0	3	3	763	969	U	Q - U
1.0	74.0	2 3/8	4	704	945	UV	U
Rich Formula, Without Malt							
Control	76.5	5 1/8	1 - 2	---	935	------	S
0.3	77.3	3 7/8	2 - 3	---	943	----	Q - S
0.6	78.0	3	3	---	946	-----	Q
1.0	76.0	2 3/8	4	---	914	----	Q - U
Rich Formula, Without Sugar							
Control	76.3	5	1 - 2	---	940	---	S
0.3	77.1	3 7/8	2 - 3	---	963	---	Q
0.6	77.8	3	3	---	973	---	Q - U
1.0	75.8	2 3/8	3 - 4	---	947	---	U
Rich Formula, Without Sugar and Malt							
Control	77.8	4 3/4	1 - 2	---	568	---	Q - S
0.3	78.6	3 5/8	2 - 3	---	677	---	Q
0.6	79.3	3	3 - 4	---	735	---	U
1.0	77.3	2 3/8	4	---	706	---	U

1/ S, Q, U, and VU - Satisfactory, Questionable, Unsatisfactory, and Very Unsatisfactory quality with respect to property in question.

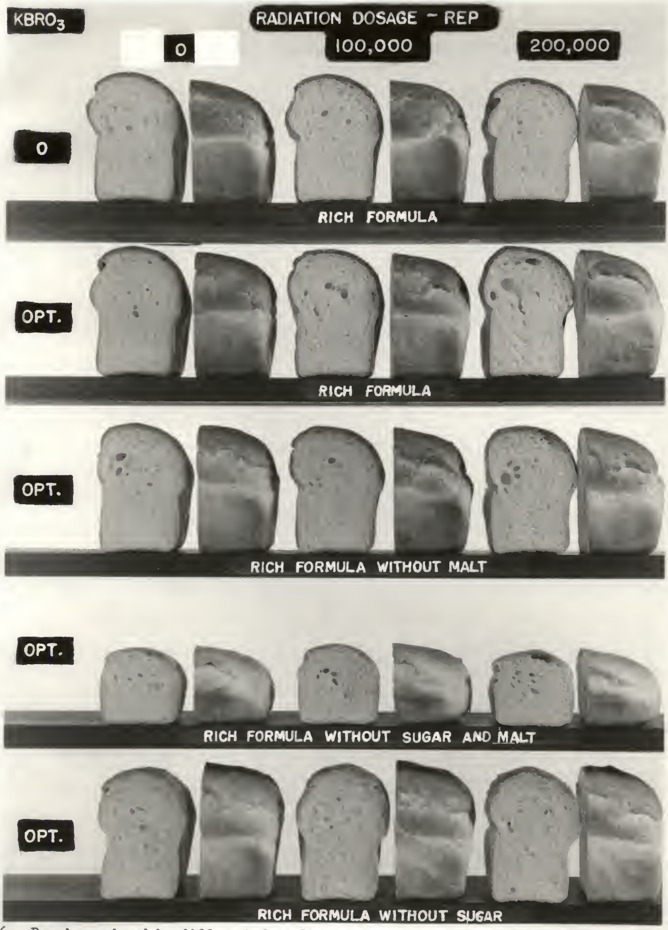

Fig. 6. Breads produced by different formulas from gamma-irradiated Bison wheat.

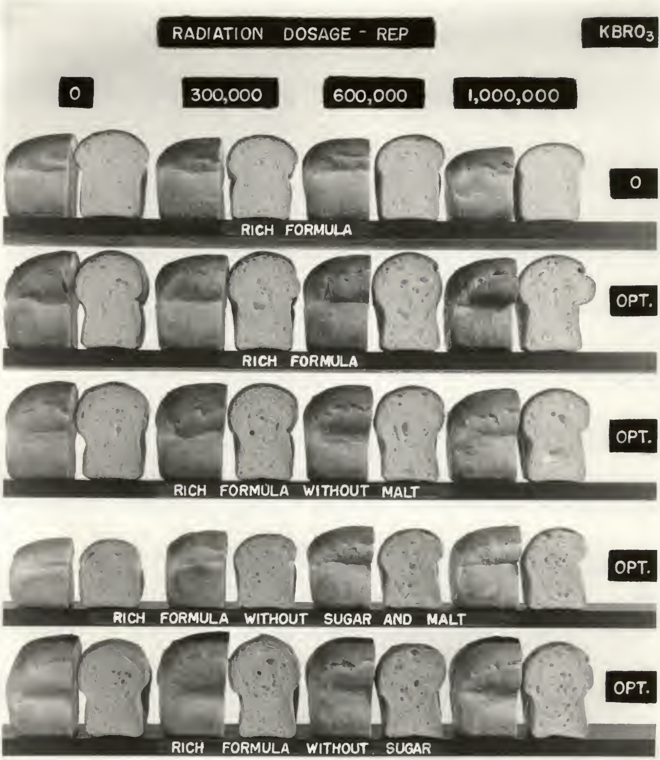

Fig. 7. Breads produced by different formulas from gamma-irradiated Bison wheat.

highest dosages, consistent increase in color and musty-like flavor were noted with increasing dosage level. After the addition of adequate amounts of potassium bromate, loaf volumes for all treatments were fully equal to that of the control. It is pertinent to note however, that the addition of bromate did not result in a recovery of crumb grain quality equal to that of the control. An increase in optimum $KBrO_3$ requirement was noted as radiation treatment increased. Thus optimum loaf volume and crumb grain structure were obtained by the addition of 4 mg. $KBrO_3$ for the 1.0×10^6 rep treatment as compared to only 2 mg. for the control. Loaf volumes differed only slightly, in general, between different treatment levels within each of the formulas 2 and 3 (without malt and without sugar, respectively). Crumb and grain, however, were progressively poorer with increasing radiation dosage. Bread produced by formula 4 (without sugar and malt) showed a regular increase in volume up through dosage level 0.6×10^6 rep but dropped again at 1.0×10^6 rep.

Physical and Baking Properties of Comanche Wheat

The baking results obtained using the commercial-type sponge formula are given in Table 6. The changes in mixing time and absorption caused by radiation treatment confirm the previous results obtained with the Bison and Conley wheat series. The texture, grain, and break and shred of bread from irradiated wheat were comparatively poorer than for untreated wheat. The bread color test also confirms the earlier observation that the color of bread was consistently darker with increasing radiation dosage.

The Taste Panel Test

Commercial one pound loaves produced from the irradiated Comanche wheat were used for six replicate panel tests. One of the seven judges was ill

Table 6. Commercial-scale baking characteristics of flours milled from irradiated Comanche wheat.

Determination	Radiation dosage, 10^6 rep 0	0.1	0.3	0.6	1.0
Protein, %	13.6	13.5	13.5	13.9	13.9
Moisture, %	12.9	12.1	11.8	12.2	12.1
Ash, %	0.41	0.42	0.46	0.46	0.44
Absorption, %	69.6	70.0	72.8	73.2	72.2
Mixing time, min.	4	3	$2\frac{1}{4}$	2	$1\frac{1}{2}$
Loaf volume, cc	3000+	2900	2820	2815	2600
Bread color, % 1/	60	56	55	52	50
Loaf score factors: 2/					
Volume	20	19	18	18	16
Crust color	10	10	10	10	10
Symmetry	9	8	8	8	8
Break and shred	8	7	7	5	5
Grain	18	14	13	10	8
Crumb color	10	9	8	6	5
Texture	18	14	14	10	8
Total loaf score	93	81	78	67	60

1/ Reflectance as percent reflection from magnesium oxide standard using Photovolt Reflectometer.

2/ The possible points: volume 20; crust color 10; symmetry 10; break and shred 10; grain 20; crumb color 10; texture 20. Maximum possible points are 100.

Table 7. Taste scores of bread from irradiated Comanche wheat.

Taste test date 1957	No. of taste panel members	Radiation dosage	Number of votes per ranking					Average[1/] score
			Best	2nd	3rd	4th	5th	
		10^6 rep						
		Control	1	2	1	3	0	2.85
		0.1	2	2	2	0	1	2.43
June 18	7	0.3	1	3	3	0	0	2.28
		0.6	3	0	1	2	1	2.71
		1.0	0	0	0	2	5	4.71
		Control	4	2	1	0	0	1.57
		0.1	1	3	2	1	0	2.43
June 21	7	0.3	0	0	4	3	0	3.43
		0.6	1	1	0	3	2	3.57
		1.0	1	1	0	0	5	4.00
		Control	5	2	0	0	0	1.28
		0.1	2	2	2	0	1	2.43
June 25	7	0.3	1	1	5	0	0	2.57
		0.6	0	1	0	5	1	3.85
		1.0	0	0	0	1	6	4.85
		Control	7	0	0	0	0	1.00
		0.1	0	2	5	0	0	2.71
June 27	7	0.3	0	3	1	3	0	3.00
		0.6	0	2	1	4	0	3.28
		1.0	0	0	0	0	7	5.00
		Control	2	2	2	0	0	2.00
		0.1	3	1	1	0	1	2.16
June 28	.6	0.3	1	2	2	1	0	2.50
		0.6	0	1	0	4	1	3.83
		1.0	0	0	1	1	4	4.50
		Control	3	1	2	0	0	1.83
		0.1	2	0	3	1	0	2.50
July 2		0.3	1	5	0	0	0	1.83
		0.6	0	0	1	5	0	3.83
		1.0	0	0	0	0	6	5.00

1/ Score of best is 1, 2nd best is 2, etc.

Table 8, Sum of average taste scores and mean average taste score of bread baked from irradiated Comanche wheat.

Radiation dosage	Average Score of Replication						Sum of average taste scores	Mean average taste scores
	I	II	III	IV	V	VI		
10^6 rep								
0	2.85	1.57	1.28	1.00	2.00	1.83	10.53	1.76
0.1	2.43	2.43	2.43	2.71	2.16	2.50	14.66	2.44
0.3	2.28	3.43	2.57	3.00	2.50	1.83	15.61	2.60
0.6	2.71	3.57	3.85	3.28	3.83	3.83	21.07	3.51
1.0	4.71	4.00	4.85	5.00	4.50	5.00	28.06	4.68

Table 9. Analysis of variance of average bread scores[1].

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	29	35.3799	
Radiation dosage of gamma-rays	4	29.7906	29.7906/4 = 7.448
Breads, same radiation dosage	25	5.5893	5.5893/25 = 0.2236

$$\text{Variance Ratio} = F = \frac{\text{Mean square of sample means}}{\text{Mean square of individuals}} = \frac{7.448}{0.2236} = 33.31^{2/}$$

1/ The calculation involved:

1. $\Sigma X = 2.85 + 1.57 + 1.28 + \ldots + 4.50 + 5.00 = 89.93$

2. $\Sigma X^2 = (2.85)^2 + (1.57)^2 + (1.28)^2 + \ldots + (4.50)^2 + (5.00)^2 = 299.7694$

3. The correction for mean:

$$C = (\Sigma X)^2/n = (89.93)^2/30 = 264.3895$$

4. The total sum of squares:

$$\Sigma X^2 - C = 299.7694 - 264.3895 = 35.3799$$

5. Sum of squares of gamma radiation dosage:

$$\frac{(10.53)^2 + (14.66)^2 + (15.61)^2 + (21.07)^2 + (28.06)^2}{6} - C = 29.7906$$

2/ Significant at 0.5% level.

Table 10. Analysis of linear component of bread scores[1]

Radiation dosage	Deviation from mean	Deviation squared	Sum of the average scores for each treatment
X	$\lambda = X - \bar{x}$	λ^2	
10^6 rep			
0	-4	16	10.53
0.1	-3	9	14.66
0.3	-1	1	15.61
0.6	+2	4	21.07
1.0	+6	36	28.06

1/ Calculation involved:

$\Sigma X = 20; \quad \bar{x} = 20/5 = 4$

Linear component of gamma-radiation effect

$$= \frac{[-4\,(10.53) - 3\,(14.65) - 1\,(15.60) + 2\,(20.22) + 6\,(28.06)]}{(16 + 9 + 1 + 4 + 36)\,(6)}$$

$$= \frac{(107.13)^2}{396} = 28.9819$$

$$F = \frac{28.9819}{0.2236} = 129.6^{***}$$

*** significant at 0.5% level

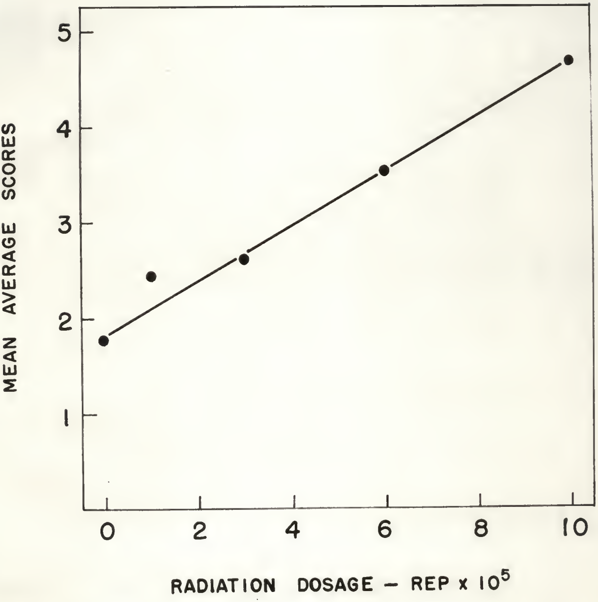

Fig. 8. The effect of gamma radiation on bread flavor.

during the last two tests. All of the scores are presented in Table 7 and a summary appears in Table 8. An analysis of variance (Table 9) and the linear component of these data (Table 10) showed that both F values are highly significant at the 0.5 per cent level. Thus, there is much less than 5 chances in 1000 of drawing a sample having a larger factor value. Clearly the samples were from populations of different mean value, and were linearly related. The conclusion is that there definitely is a decrease in desirability of the taste and flavor of bread from irradiated wheat, and this decrease is in proportion to the increase in radiation dosage. This linear relationship is shown in Fig. 8.

Crumb Compressibility of Bread Baked from Irradiated Wheat

Data pertaining to the effect of radiation on bread crumb compressibility are presented in Table 11 and 12. The data in Table 11 were obtained 2 hours after baking and those in Table 12 were for duplicate loaves 24 hours after baking. An analysis of variance (Table 13) of these data revealed that significant differences in the bread crumb compressibilities were produced by gamma-radiation. The compressibility of the bread was decreased linearly with increasing radiation dosage as revealed by data in Fig. 9 and the analysis of linear component in Table 13. Staling rate, computed as increase in resistance to compression, showed an increase with increasing dosage level, except for an anomolous value at the 0.3×10^6 rep treatment (Table 14).

DISCUSSION AND CONCLUSIONS

Fatty acid content is unchanged by radiation, indicating that radiation does not produce fat hydrolysis. Fluorescence increased slightly only at the 1 megarep dosage level, thus confirming the conclusion of Yen and Milner (60),

Table 11. Two hour compressibility values for bread baked from flours representing different levels of irradiation.

Radiation dosage 10^6 rep	Loaf no.	Compressibility values 1/ gms	gms	gms	gms	gms	gms	Mean gms	Group mean gms
Control	A_1	39.2	42.0	38.1	36.6	35.9	37.6	38.4	
	B_1	40.7	36.1	35.2	37.2	35.1	36.8	36.9	39.4
	C_1	46.9	39.2	39.8	36.2	42.3	39.7	40.6	
	D_1	43.2	41.9	46.7	39.1	41.7	39.2	41.9	
	A_2	42.6	40.4	41.6	47.4	42.1	43.3	42.8	
0.1	B_2	41.5	40.2	43.5	40.4	41.7	41.8	41.5	42.0
	C_2	41.8	42.3	42.5	40.9	41.9	42.1	41.9	
	D_2	42.0	43.2	41.2	41.2	43.6	40.2	41.9	
	A_3	54.6	49.3	37.4	43.0	58.6	51.1	49.0	
0.3	B_3	45.6	46.8	48.1	44.8	49.5	45.2	46.6	48.9
	C_3	47.1	50.5	48.8	47.9	47.1	48.9	48.3	
	D_3	53.7	48.2	55.3	50.1	53.8	49.6	51.8	
	A_4	46.3	50.7	49.9	44.7	50.2	49.8	48.6	
0.6	B_4	52.7	50.3	50.2	50.6	52.1	52.5	51.4	50.2
	C_4	48.6	46.4	48.1	52.1	44.8	53.0	48.8	
	D_4	53.1	52.8	51.3	51.1	49.6	54.1	52.0	
	A_5	72.7	65.2	75.2	71.1	72.6	71.0	71.3	
1.0	B_5	58.4	62.3	61.6	64.9	63.4	68.5	63.1	68.6
	C_5	72.6	59.8	72.9	68.3	73.2	75.2	70.3	
	D_5	70.0	69.4	73.1	68.9	68.5	67.8	69.6	

1/ Each value is grams of lead shot required to press a one inch plunger 4 m.m. into the bread crumb.

Table 12. Twenty-four hour compressibility values for bread baked from flours representing different levels of irradiation.

Radiation dosage	Loaf no.	Compressibility values 1/						Mean	Group mean
		gms	gms	gms	gms	gms	gms	gms	gms
10^6 rep									
Control	A_1	63.5	63.6	62.7	65.9	66.6	64.4	64.4	64.6
	B_1	62.2	70.3	63.1	60.1	62.3	62.5	63.4	
	C_1	65.3	64.8	67.2	65.4	62.8	63.4	64.8	
	D_1	64.8	60.0	61.0	71.9	70.4	65.6	65.6	
0.1	A_2	68.3	65.0	70.7	75.6	79.7	83.1	75.5	73.1
	B_2	78.5	69.9	69.8	79.2	73.5	75.2	74.6	
	C_2	75.1	70.1	70.8	71.1	68.7	68.4	70.8	
	D_2	68.7	71.3	67.7	71.3	78.2	72.6	71.6	
0.3	A_3	74.9	75.4	74.7	77.1	76.9	85.1	77.4	77.2
	B_3	79.9	68.1	84.1	85.9	75.2	70.6	77.3	
	C_3	85.7	78.4	97.5	74.9	76.1	71.5	80.6	
	D_3	85.1	74.1	72.9	67.6	69.4	72.8	73.6	
0.6	A_4	90.3	91.9	89.1	92.6	85.6	95.2	90.8	89.7
	B_4	92.9	87.1	90.2	86.5	87.1	83.4	87.8	
	C_4	97.5	100.6	87.7	97.3	95.3	86.9	94.2	
	D_4	89.4	84.6	86.3	85.7	87.4	83.2	86.1	
1.0	A_5	137.5	134.8	121.0	117.1	123.6	128.4	127.1	115.4
	B_5	93.5	93.2	85.3	96.9	94.7	102.9	94.4	
	C_5	129.0	125.4	118.6	118.2	113.7	98.6	117.2	
	D_5	126.8	130.5	116.3	129.4	107.9	126.3	122.8	

1/ Each value is grams of lead shot required to press a one inch plunger 4 m.m. into the bread crumb.

Table 13. Analysis of variance and linear component of two hour compressibility values for bread baked from flours representing different levels of irradiation.

Source of variation	Degree of freedom	Sum of squares	Mean squares
Total	19	2164.51	
Radiation dosage	4	2083.97	520.99
Bread, same radiation dosage	15	80.54	53.5
[Linear component	1	1942.42	1942.42]

Variance Ratio: $F = 520.99/53.5 = 9.37$***

Linear Component: $F = 1942.42/53.5 = 36.3$***

*** Significant at 0.5% level.

Table 14. The effect of gamma-irradiation on staling rate of bread baked from flours representing different dosage levels.

Radiation dosage	Group means		Difference	Average[1/] staling rate
	24 hrs.	2 hrs.		
10^6 rep	gm	gm	gm	gms/hr
Control	64.6	39.4	25.2	1.15
0.1	73.1	42.0	31.1	1.41
0.3	77.2	48.9	28.3	1.29
0.6	89.7	50.2	39.5	1.80
1.0	115.4	68.6	46.8	2.13

1/ Difference between 24 and 2 hours group means divided by the time difference.

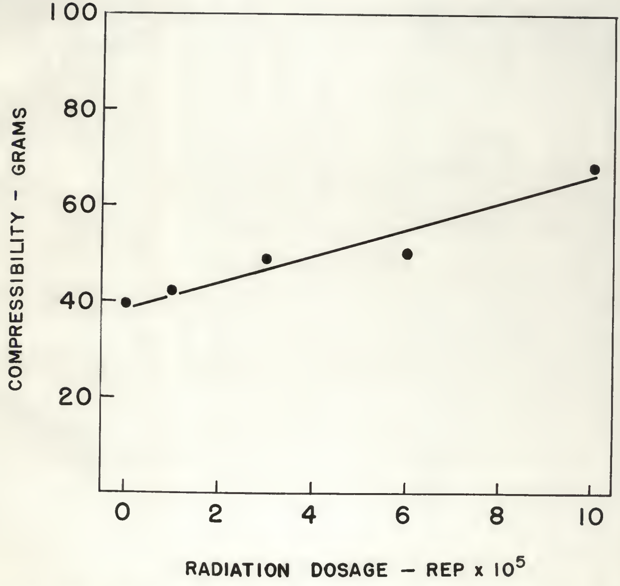

Fig. 9. The regression of gamma radiation dosage on bread compressibility.

that heavy dosages of irradiation initiate a browning reaction in wheat. This is further confirmed by the observed loss in carotenoid pigment content of flour which occurs with irradiation, even as the treated flour, as revealed by the Kent-Jones Color Grader becomes darker due to a browning reaction. As indicated by Yen and Milner's work (60), a considerable increase in fluorscence occurred in grain at a dosage level 1,875,000 rep. McWilliams also observed a darkening in bread baked from irradiated flour (McWilliams, et. al. 41).

The apparent increase in wheat riboflavin at the highest dosages of irradiation (Table 3) is difficult to rationalize in view of the sensitivity of this vitamin to radiation damage. Inasmuch as the method used for the determination involves fluorescence measurements, it appears most likely that the increase noted is a reflection of the increase in fluorescence due to a browning reaction as previously noted.

Loss of gluten hydration capacity as indicated by sedimentation value was obvious in the Conley series but not in the Bison series. Probably the lower radiation dosage level and the lower gluten quality of the Bison wheat was responsible for the lack of change in the sedimentation value. Damage to the protein also was manifested in a slight increase in non-protein nitrogen as well as a reduction in dough mixing requirements. In general, however, modification in protein properties due to irradiation was nominal in comparison with the effects on the starch fraction.

It is particularly pertinent to point out the questionable to unsatisfactory crumb grain obtained when bromate was omitted from the formula. An increasing reducing effect with increasing dosage is indicated. With amounts of bromate adequate for complete loaf volume recovery, however, the questionable to unsatisfactory crumb grains with open, heavy, and contrastable cell structure

suggested impairment and overoxidation. Thus, the apparent reducing effect of radiation in terms of reduced loaf volumes and underdeveloped crumb grain at the zero bromate level does not follow the generally accepted concept of the effects of reduction on bread flours, because the apparently underdeveloped crumb grains do not recover along with loaf volume to equal the characteristics of the control when bromate is added. Thus, in addition to a reducing effect, radiation adversely and irreversibly affects the flour in a manner that differs from the conventional reversible reduction-oxidation concept.

The experimental results reveal that starch is degraded by radiation to short chain fragments including simple sugars. Thus the starch becomes more susceptible to amylase enzyme action, which in turn would increase the maltose value as well as the dextrin content and, in addition, would decrease the maximum starch gelatinization viscosity of treated flour.

Increases in absorption with increasing dosage up to 0.6×10^6 rep, as shown by both farinograph and baking test, also can be attributed to starch damage by radiation. At the highest dosage (1.0×10^6 rep), the absorption decreased, apparently due to an effect of radiation on some other constituents of wheat.

The major degradation of starch due to irradiation suggests that the polysaccharides of the wheat are the fractions most drastically affected. In this work starch damage was reflected by a number of factors including a decrease in actual starch content at high irradiation level (Table 3), a drop in gelatinization viscosity, the increase in dextrin and a decrease in their chain length, an increase in reducing sugars, and a stimulation in gas production when flour-water dough is fermented with yeast. This starch degradation, however, was not sufficient even at one million reps to eliminate the re-

quirement for additional sugar (for optimum fermentation and loaf volume) which is normally supplied either by added sugar or by an amylase enzyme supplement. Neither did the starch degradation result in increased softness of bread crumb or in retardation of staling, which are benefits usually associated with moderate starch hydrolysis due to alpha amylase supplementation during the baking process. In fact, and unexpectedly, radiation damage to starch significantly reduced crumb softness, and staling rate was increased in proportion to radiation dosage. These apparently anomalous results suggest that starch modification by irradiation is not a simple hydrolytic process, but may involve other complex chemical transformations as well.

The peculiar response to potassium bromate of flour milled from irradiated wheat suggests that compounds other than protein and starch are involved in this effect. Pentosans, for example, being complex polysaccharides similar to starch, may also be seriously altered by radiation. Flour contains approximately 1 per cent of water-soluble pentosans which have been shown to form irreversible gels upon treatment with oxidizing agents such as potassium bromate. This gel-forming characteristic of pentosans in response to bromate may promote dough rigidity and therefore enhance the cellular structure of bread. The unusual response of radiated flour to bromate whereby crumb grain remains poor while loaf volume is increased, may well involve the damaging effect of radiation on pentosans.

Investigations also are warranted concerning the possible effects of radiation on sulfhydryl groups in flour in relation to oxidation-reduction changes in dough. The precise effects of radiation treatment of wheat and flour probably would be approached best by an investigation of flour fractions individually irradiated.

SUMMARY

Two hard red winter wheat varieties (Bison and Comanche) and one hard red spring wheat variety (Conely) were treated with gamma-rays at various levels up to one megarep.

Chemical, physical, and baking changes associated with such treatments were evaluated. The following results were obtained.

The flours from treated wheats were higher in non-reducing sugar content, but there was little or no difference between the various dosage levels.

Reducing sugar, maltose value (diastatic activity) and dextrins of reduced glucose chain length, in general, showed an increase with increasing dosage level. These results suggest that the starch fraction of flour is degraded by radiation to smaller fragments.

The significance of the small decreases observed in fatty acids with increasing radiation is not known.

Conley wheat flour with 1 megarep treatment showed a slight increase in fluorescence; however, no significant change was found in the Bison series.

Amylograph tests revealed a marked reduction in maximum gelatinization viscosity of flour in direct proportion to radiation treatment.

Farinograph tests showed that water absorptions of irradiated flours were higher than the controls, whereas dough development time generally decreased with increasing radiation dosage particularly for the Conley series. The mixing tolerance index remained approximately constant in the Bison series, but showed an increase for the Conley variety at the 0.6 and 1.0 megarep dosage level.

Swelling capacity of flour gluten in lactic acid as revealed by the

sedimentation test decreased consistently with increasing dosage levels for the Conley series, indicating an adverse effect of radiation on the flour proteins.

The color of treated flours and resulting bread was darker in comparison with the corresponding controls, but the carotenoid pigment content was lower. The darker color is attributed to a non-enzymatic browning reaction.

No significant change of riboflavin content was found in Bison series, but a considerable increase at the highest dosage (1 megarep) was observed in the Conley series. It is believed that an increase in fluorescence due to browning was responsible for this apparent increase in riboflavin.

The starch content decreased markedly at the highest dosage of radiation in the Conley series. No apparent change was found in the Bison series.

A regular increase in non-protein nitrogen was correlated with increased radiation dosage. This increase may be attributed to radiation damage to the protein fraction.

The irradiated flour from the Conley series showed a higher gas production rate than the controls, suggesting that more sugar was available due to enzymatic action on degraded starch.

Dough mixing time observed during pup loaf and commercial scale baking tests confirmed the farinograph data, showing a regular decrease with radiation dosage.

Baking absorption for Bison wheat increased slightly at 100,000 rep but at a dosage level of 200,000 rep was lower that the controls. In the case of Conley wheat , the water absorption increased progressively up to 600,000 rep but at the maximum dosage of 1 megarep was slightly less than the control.

Bread baked from irradiated wheat by a rich formula at zero bromate level

exhibited progressively poorer crumb grain and lower volume with increasing doses of radiation.

The potential loaf volume of flour from treated wheat was regained by the addition of adequate amounts of bromate, but crumb grain remained relatively poorer than the controls in terms of coarser grain, darker color, and off flavor.

At optimum bromate levels, no significant difference in loaf volume was found between different treatment levels when either the rich formula, rich formula without malt, or rich formula without sugar were used. Crumb grains, however, were progressively poorer with increasing radiation dosage.

Evidence that radiation causes starch to become available to amylase action, thus releasing sugar for yeast fermentation was found by omitting sugar and malt from the rich formula. The bread produced by this formula showed a regular increase in volume up through a dosage level 0.6×10^6 rep, but dropped somewhat at 1.0×10^6 rep. The best loaf volume, however, was well below that in which adequate amounts of malt and/or sugar were used.

Reduction in mixing time and increases in water absorption due to radiation, as revealed in the commercial-scale baking tests, confirmed the findings of the pup loaf baking tests and the farinograph data.

Bread produced on a commercial-scale from irradiated Comanche wheat also was progressively poorer in grain and loaf volume with increasing radiation levels.

The panel test of the effect of radiation on bread flavor indicated that flavor desirability decreased linearly with increasing radiation dosage.

Crumb compressibility of bread decreased regularly with increasing radiation dosage at both 2 and 24 hours after baking.

Rate of staling of bread from irradiated wheat flour was more rapid than the controls, indicating that starch modification by irradiation differs from that produced by amylase enzymes.

ACKNOWLEDGMENTS

Acknowledgement and sincere thanks are extended to Dr. Max Milner, major instructor, and to Professor Karl F. Finney for their help and counsel in carrying out these experiments and in the preparation of this report.

Appreciation is due to Dr. John A. Johnson, for offering helpful suggestions; to Dr. H. C. Fryer, Department of Mathematics, for providing statistical data; to Dr. W. S. Ruliffson, Department of Chemistry for his kind assistance in the analytical work; and to Dr. John A. Shellenberger, Head, Department of Flour and Feed Milling Industries for providing research facilities.

The writer is also indebted to Mr. Donald Miller, Mr. M. D. Shogren, and Mrs. M. H. Maurer for their kind assistance with the baking tests.

LITERATURE CITED

(1) Afanaseva, A. S.
The action of x-rays on air-dry, moist and germinated wheat grains (Russian). Bull. Soc. Naturalistes Moscow, Sect. Biol. 48: No. 1, 19-28, 1939. Chem. Abstract, 38: 5529, 1944.

(2) American Association of Cereal Chemists Cereal Laboratory Methods, 5th Ed. 1947.

(3) American Association of Cereal Chemists Cereal Laboratory Methods, 6th Ed. 1957.

(4) Arnason, T. J.
Radiation induced mutation in wheat and barley. Canadian Journal of Botany, 30: 743-754, 1953.

(5) Association of Official Agricultural Chemists Official Methods of Analysis, 7th Ed. 1950.

(6) Barron, E. S. G., and S. Dickman.
Inhibition of sulfhydryl enzymes by alpha, beta and gamma-rays J. Gen. Physiol. 32: 595, 1949.

(7) Barron, E. S. G., L. Seki and P. Johnson.
Studies on the mechanism of action of ionizing radiation VIII, Effect of hydrogen peroxide on cell metabolism, enzymes and proteins. Arch. Biochem. Biophys. 41: 188, 1952.

(8) Barron, E. S. G., D. Sherman, J. A. Muntz and T. P. Singer.
Studies on the mechanism of action of ionizing radiation. I. Inhibition of enzymes by x-rays. J. Gen. Physiol 32: 537, 1949.

(9) Bassenge, W.
Alteration of the nutritional value of wheat protein by irradiation with the gamma-rays of mesothorium (Original in German). Arch. fur Verdaungs - Krankheiten 61: 66-73. Chem. Abs. 31: 8630, 1937.

(10) Bauman, H. E., H. Boeder, A. S. Taylor, C. G. Harrel and R. A. Loren.
Effect of gamma-irradiation on the cake mixes of high and low moisture levels. Food Tech. 11: 193, 1957.

(11) Benedict, M., and H. Kersten.
The effect of soft x-rays on the germination of wheat seeds. Physical Review, 45: 125, 1934.

(12) Brownell, L. H., H. A. Harson and J. V. Nehemias.
A preliminary study of the effect of gamma-radiation on the baking quality of flours. Food Tech. 9: 620, 1955.

(13) Bovie, W. T.
Coagulation of proteins by ultraviolet light. Science 37: 373, 1913.

(14) Charlesby, A.
The degradation of cellulose by ionizing radiation. Nuclear Science Abstract 8: 3288, 1954.

(15) Clark, G. L., and L. W. Pickett.
Some new experiments on the chemical effects of x-rays and the energy relations involved. J. Am. Chem. Soc. 52: 465, 1930.

(16) Cole, E. W., and M. Milner.
Colorimetric and fluorometric properties of wheat in relation to germ damage. Cereal Chem. 30: 378-391, 1953.

(17) Dale, W. M.
Deamination of aqueous solution of L-serine by x-radiation. Nature, 166: 1121, 1950

(18) Feinstein, R. N., and L. L. Nejelski.
Alginic acid as a model of testing the effects of radiomimetric agents. Radiation Research, 2: 8, 1955.

(19) Finney, K. F.
Methods of estimating and the effect of variety and protein level on the baking absorption of flour. Cereal Chem. 22: 149-158, 1945.

(20) Finney, K. F., and M. A. Barmore.
Yeast variability in wheat variety test baking. Cereal Chem. 20: 194-200, 1943.

(21) Finney, K. F., and M. A. Barmore.
Varietal response to certain baking ingredients essential in evaluating the protein quality of hard winter wheats. Cereal Chem. 22: 225-243, 1945.

(22) Finney, K. F., and M. A. Barmore.
Optimum vs. fixed mixing time at various potassium bromate levels in experimental bread baking. Cereal Chem. 22: 244-254, 1945.

(23) Fricke, H.
The chemical properties of x-ray activated molecules with special references to the water molecule. Cold Spring Harbor Symposia on Quantative Biology, 2: 241, 1934.

(24) Giles, K. A., H. D. Kaslow and J. S.
Some observations on the effect of ionizing radiation on flour and its components. Am. Assoc. of Cereal Chemists, Abstract of paper presented at 41st annual meeting, May, 1956.

(25) Hassett, C. C.
Current status of insect control by radiation. Acience 124: 1011, 1956.

(26) Hassett, C. C., and D. W. Jenkins.
Use of fission products for insect control. Nucleonics 10: No. 12, 42, 1952.

(27) Hollaender, A.
Radiation Biology. New York: McGraw - Hill, 1954.

(28) Holtz, P., and J. P. Becker.
Action of x-rays on glucose. Arch. Exptl. Pathol. Pharmakol. 182: 160, 1936.

(29) Johnson, J. A.
Amylograph Standardization. Transactions, American Association of Cereal Chemists. 12: 292, 1954.

(30) Kent-Jones, D. W., A. J. Amos, and W. Martin.
Recording of flour grade by measurement of reflecting power. Analyst, 75: 133, 1950.

(31) Key, J. M.
The biological action of x-rays and fast neutrons on barley and wheat. Arkiv. Botanik, 1: 545, 1952. Nuclear Science Abstracts, 7: 5, 1953.

(32) Koch, R. B., W. F. Geddes, and F. Smith.
The sugars of the flour of wheat (Triticum vulgare). Cereal Chem. 28: 424, 1951.

(33) Lawton, E. J., W. D. Bellamy, R. E. Hungate, M. P. Bryant and E. Hall.
Effect of high-velocity electrons on wood. Science 113, 380, 1951.

(34) Lloyd, N. E., M. Milner and K. F. Finney.
Treatment of wheat with ionizing radiations. I. Some effects of x-rays on gluten and gluten sols. Cereal Chem. 34: 55-62, 1957.

(35) Maes, E., and M. Bauwen.
Action of ultraviolet rays on flour. I. Baking value. (orginial in French). Bulletin de l ecole de la menunerie belge, 13: 14-22, 1951. Chem. abs. 45: 5330, 1951.

(36) Maes, E., and M. Bauwen.
Influence of infrared radiation in the keeping qualities of wheat germs (original in French). Bulletin de lecole de la meunerie belge, 13: 125-33, 1951. Chem. Abs. 46: 1662, 1952.

(37) Maes, E., M. Bauwen, A. R. Beschrgider, and S. V. D. Driessche.
General view of the present state of an investigation on the action of ultraviolet rays on flour (original in German). Getreide, Mehl und Brot, 4: 253-55, 1950. Chem. Abs. 47: P8919, 1953.

(38) Maes, E., M. Bauman, A. R. Deschreider and S. V. D. Driessche.
The effect of ultraviolet rays on flour. Food Manufacture (London), 27: 1120-1125, 1952.

(39) Maes, E.
The effect of ultraviolet rays on the baking value of flour, survey of obtained results (original in French). Chem. Abs. 47: 2391, 1953.

(40) Maes, E.
Influence of ultraviolet rays on flour. VIII. The fatty substances (original in French). Chem. Abs. 47: 2391, 1953.

(41) McWilliams, C. S., A. R. Felsher, R. Pomerantz and T. T. McMullen.
Exploratory studies on the effect of ionizing radiation upon the baking properties and storage stability of an unbleached winter wheat bread flour. American Association of Cereal Chemists, Abstract of paper presented at 41st Annual Meeting, May 1956.

(42) Miller, B. S., J. A. Johnson and D. L. Palmer.
A comparison of cereal, fungal, and bacterial alpha-amulase as supplements for breadmaking. Food Technology, 7: 38, 1953.

(43) Milner, Max and Yin-Chao Yen.
Treatment of wheat with ionizing radiation. III. The effect on breadbaking and related properties. Food Technology. 10: 528, 1956.

(44) Morgan, B. H.
Current status of radiation preservation of foods. Food Processing, 18: 6, 1957.

(45) Mukherjee, S.
A new detecting reagent for simple sugars. Nature, 169: 330, 1952.

(46) Phillips, G. O.
Action of ionizing radiation on aqueous solutions of carbohydrates. Nature, 173: 1044, 1954.

(47) Price, F. P., W. D. Bellamy and E. J. Lawton.
Effect of high velocity electrons on dry dextran. J. Phys. Chem. 58: 821, 1954.

(48) Proctor, B. E. and S. A. Goldblith.
Electromagnetic radiation fundamentals and their applications to food technology. Advances in Food Research, 3: 119, 1951.

(49) Proctor, B. E., E. E. Lockhart, S. A. Goldblith, A. V. Grundy, G. E. Tripp, M. Karl and R. C. Brogle.
The use of ionizing radiation in the eradication of insects in packed military rations. Food Technology. 8: 536, 1954.

(50) Ricketts, C. R., and C. E. Rowe.
Effect of gamma-rays on dextran. Chemistry and Industry, 189, 1954.

(51) Risse, O.
Chemical action of x-rays in aqueous solution. Ergebn. Physiol. 30: 242, 1930. Chem. Abs. 25: 2366, 1931.

(52) Roberts, E. A.
The effect of irradiation on starch and starch grain. Plant Physiology, 31: supplement, 11, 1956.

(53) Saeman, J. F., M. A. Millett and E. J. Lawton.
Effect of high energy cathode rays on cellulose. Ind. Eng. Chem. 44: 2848, 1952.

(54) Schoenberg, M. D., R. E. Brookes, J. J. Hall and M. Scheneiderman.
Effect of x-ray irradiation on the hyaluronidase-hyaluronic acid system. Arch. Biochem. 30: 333, 1951.

(55) Snedecor, G. W.
Statistical Methods, Ames, Iowa: The Iowa State College Press, 1956.

(56) Spiegel, A. M.
Physico-chemical studies on irradiation of proteins. IV Influence of short wave radiations on the absorption capacity of serum and serum proteins in the ultraviolet. Biochem. 213: 475, 1929.

(57) Svedberg, T., and S. Brohult.
Splitting of the hemocyanin molecule by ultraviolet light. Nature, 143: 939, 1939.

(58) Weiss, J.
Radiochemistry of aqueous solutions. Nature, 153: 748, 1944.

(59) Weiss, J.
Aspects of the chemical and biological action of radiation. Faraday Soc. Trans. 43: 314-24, 1947.

(60) Yen, Y. C., M. Milner and H. T. Ward.
Treatment of wheat with ionixing radiations. II. Effects on respiration and other indices of storage deterioration. Food Technol. 10: 411-415, 1956.

INFLUENCE OF GAMMA RADIATION ON WHEAT
AND FLOUR PROPERTIES

By

SING-PING LAI

B.S., National Taiwan University, Taipei, Formosa, 1954

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Flour and Feed Milling Industries

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1958

Two hard red winter wheat varieties (Bison and Comanche) and one hard red spring wheat variety (Conley) were treated with gamma rays at various levels up to one megarep.

Chemical, physical, and baking changes associated with such treatments were evaluated. The following results were obtained.

The flours from treated wheats were higher in non-reducing sugar content, but there was little or no difference between the various dosage levels.

Reducing sugar, maltose value (diastatic activity) and dextrins of reduced glucose chain length, in general, showed an increase with increasing dosage level. These results suggest that the starch fraction of flour is degraded by radiation to smaller fragments.

The significance of the small decreases observed in fatty acids with increasing radiation is not known.

Conley wheat flour with 1 megarep treatment showed a slight increase in fluorescence; however, no significant change was found in the Bison series.

Amylograph tests revealed a marked reduction in maximum gelatinization viscosity of flour in direct proportion to radiation treatment.

Farinograph tests showed that water absorptions of irradiated flours were higher than the controls, whereas dough development time generally decreased with increasing radiation dosage, particularly for the Conley series. The mixing tolerance index remained approximately constant in the Bison series, but showed an increase for the Conley variety at the 0.6 and 1.0 megarep dosage level.

Swelling capacity of flour gluten in lactic acid as revealed by the sedimentation test decreased consistently with increasing dosage levels for the Conley series, indicating an adverse effect of radiation on the flour proteins.

The color of treated flours and resulting bread was darker in comparison with the corresponding controls, but the carotenoid pigment content was lower. The darker color is attributed to a non-enzymatic browning reaction.

No significant change of riboflavin content was found in Bison series, but a considerable increase at the highest dosage (1 megarep) was observed in the Conley series. It is believed that an increase in fluorescence due to browning was responsible for this apparent increase in riboflavin.

The starch content decreased markedly at the highest dosage of radiation in the Conley series. No apparent change was found in the Bison series.

A regular increase in non-protein nitrogen was correlated with increased radiation dosage. This increase may be attributed to radiation damage to the protein fraction.

The irradiated flour from the Conley series showed a higher gas production rate than the controls, suggesting that more sugar was available due to enzymatic action on degraded starch.

Dough mixing time observed during pup loaf and commercial scale baking tests confirmed the farinograph data, showing a regular decrease with radiation dosage.

Baking absorption for Bison wheat increased slightly at 100,00 rep but at a dosage level of 200,000 rep was lower than the controls. In the case of Conley wheat, the water absorption increased progressively up to 600,000 rep but at the maximum dosage of 1 megarep was slightly less than the control.

Bread baked from irradiated wheat by a rich formula at zero bromate level exhibited progressively poorer crumb grain and lower volume with increasing doses of radiation.

The potential loaf volume of flour from treated wheat was regained by the addition of adequate amounts of bromate, but crumb grain remained relatively poorer than the controls in terms of coarser grain, darker color, and off flavor.

At optimum bromate levels, no significant difference in loaf volume was found between different treatment levels when either the rich formula, rich formula without malt, or rich formula without sugar were used. Crumb grains, however, were progressively poorer with increasing radiation dosage.

Evidence that radiation causes starch to become available to amylase action, thus releasing sugar for yeast fermentation was found by omitting sugar and malt from the rich formula. The bread produced by this formula showed a regular increase in volume up through a dosage level 0.6×10^6 rep, but dropped somewhat at 1.0×10^6 rep. The best loaf volume, however, was well below that in which adequate amounts of malt and/or sugar were used.

Reduction in mixing time and increases in water absorption due to radiation, as revealed in the commercial-scale baking tests, confirmed the findings of the pup loaf baking tests and the farinograph data.

Bread produced on a commercial scale from irradiated Comanche wheat also was progressively poorer in grain and loaf volume with increasing radiation levels.

The panel test of the effect of radiation on bread flavor indicated that flavor desirability decreased linearly with increasing radiation dosage.

Crumb compressibility of bread decreased regularly with increasing radiation dosage at both 2 and 24 hours after baking.

Rate of staling of bread from irradiated wheat flour was more rapid than the controls, indicating that starch modification by irradiation differs from that produced by amylase enzymes.